Light that heats

Two centuries of infra-red

By Gregg Grant

Radiation

There are three types of radiation: firstly the visible variety, secondly the invisible kind and finally *actinic* radiation. Infra-red is radiation of the second kind, noticeable by its heating effect. All three types share four characteristics.

To begin with they can be transmitted through space; secondly they can be refracted; thirdly they can be reflected and finally they are obstructed by a black surface. This last explains — for example — why the photographic plate is a 'negative'.

William Herschel

In 1800 the astronomer William Herschel's paper *An investigation of the powers of prismatic colours to heat and illuminate objects* outlined his discovery of Infra-red radiation. He had been conducting an experiment to discover the heating power of different parts of the spectrum.

He had begun by passing sunlight through a prism with "… thermometers set up on the table beyond the red end of the spectrum," [1] his aim being to determine if some of the colours in his spectrum gave out more heat than others. His apparatus is illustrated in **Figure 1**.

As he moved towards the red end of the electromagnetic spectrum, he noted that his thermometers registered a rise in temperature. Herschel then moved the thermometer past the red end of the spectrum so as to note where, exactly, the heating effect disappeared.

However, exactly the reverse happened, the temperature rising higher still. Consequently the region came to be known as the *Infra-red,* or *Beyond the red,* Infra being the Latin word for below.

Why below? Simply because red light contains less energy than any other form of visible light and, in terms of energy content, is at the bottom rung. Infra-red, having even less energy, is below it.

Infra-red wavelengths

The infra-red wavelengths extend from the limit of the visible spectrum, known as the *Near Region,* to the shortest microwaves, or the *Far Region,* as illustrated in **Figure 2**.

Formerly, light wavelengths were measured in Ångstrom units, after the Swedish physicist and astronomer Anders Jöns Ångstrom, a pioneer of spectroscopy.

Figure 2 illustrates the wavelengths of the various colours in the light spectrum in both Ångstrom units and nano-metres — where one nmetre is equal to 10 Å — which have largely superseded them. Red light is refracted the least; orange, yellow, green and blue are refracted in increasing amounts whilst violet is the colour refracted to the greatest extent.

Having discovered the phenomenon, Herschel was at something of a loss when it came to interpreting what he'd found. Initial impressions among the scientific community were that the sun — apparently — emitted heat rays as well as light rays, the former being refracted to a lesser degree than the latter.

Macedonio Melloni

Some fifty years after Herschel's paper was published, the Italian physicist Macedonio Melloni began to answer many of the questions relating to infra-red radiation. In 1846, he had already measured the heating effect of the sun's light, reflected from the moon at night.

Melloni was also the inventor of the Thermopile, a series of strips of different metals — he used blocks of bismuth and antimony — that produced electric currents when one end was heated. This device enabled physicists to detect not only very weak electric currents, but also very weak heating effects.

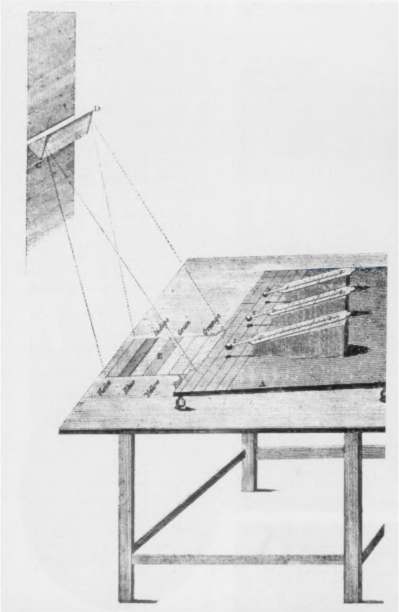

Figure 1. Herschel's apparatus for determining the heating effect of the solar spectrum. (courtesy Ann Ronam Picture Library. Taunton, Somerset).

In 1850, Melloni used his invention to detect Herschel's infra-red radiation every bit as delicately as the human eye can detect light. He shortly demonstrated that infra-red displayed all the properties of white light such as interference and polarisation. Therefore infra-red was a wave phenomenon, just as light was, but with this difference: the waves were too long to have an effect on the retina of the human eye.

Yet if "… we had the capacity to use infra-red light, there would be no darkness for us. Even on the blackest nights, every object would be visible, lit by a radiance as great as that provided by a full moon, but with a weird difference. There would be no shadows on the ground, because earth itself would be the principal source of light."

Infra-red becomes better understood

In 1879, the Austrian physicist Josef

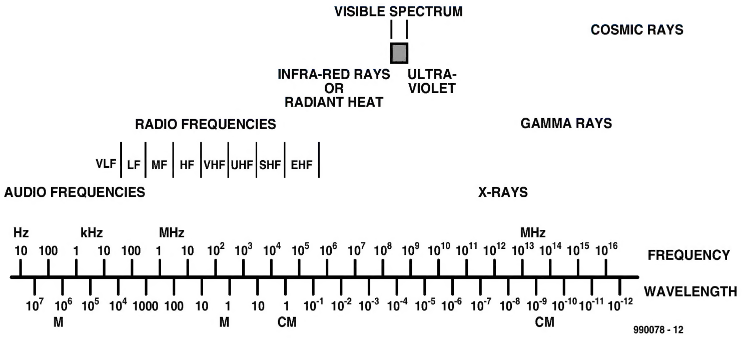

Figure 2. The electromagnetic spectrum, illustrating the location of the infra-red region.

Stefan — who'd been studying the nature of hot bodies, particularly their method of cooling — demonstrated that a body's total radiation was proportional to the fourth power of its temperature. This came to be called Stefan's Law.

Five years later, Stefan's former laboratory assistant, Ludwig Boltzmann, showed that Stefan's Law could be proven from first principles and so it came to be called the Stefan-Boltzmann Law. If, for example, a body's temperature tripled from 1,000 to 3,000 K, its radiant output would increase by 3x3x3x3, or 81 times. This meant that no matter how cold a radiating source was, it could still be detected because, when studied at infra-red, it would seem as bright as if its temperature were multiplied by itself four times!

This of course was a very speedy rise indeed, one which surprised the scientific community of the day. Nevertheless the law was soon put to the test, as a technique for establishing the surface temperature of the sun. This turned out to be around 5,700 K.

Another early application of infra-red was in photography. In 1887 William Abney, the renowned British photographic scientist and discoverer of the Abney Effect, developed techniques for detecting infra-red radiation with photographs and used them to observe the sun's spectrum, far into this particular area of the solar spectrum.

In 1905, the American astronomer-physicist William Coblentz became Chief of the Radiometry Section of the National Bureau of Standards, a post he'd retain for the next 40 years. With his colleagues Edison Pettit and Seth Barnes Nicholson, he concentrated primarily on infra-red spectroscopy. Throughout the 1920s, they carried out the first systematic infra-red observations of stellar objects, among which were not only stars and planets, but also gas clouds and nebulae.

In the course of this work, Coblentz became the first man to accurately establish the constants of black body radiation, thus confirming Planck's Law. Nicholson too had a distinguished career in planetary science, becoming the discoverer of the ninth, tenth and eleventh moons of Jupiter. These observations were possible of course because the "...infra-red range of the spectrum is so sensitive that it can detect objects whose temperatures are only a few degrees above absolute zero." [3] And no-where has this been more evident than in aerospace science.

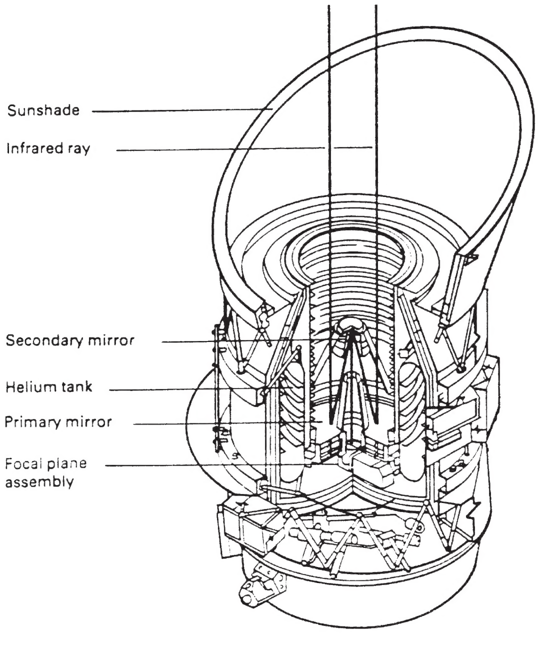

Figure 3. The IRAS satellite.

The Space Age

On April 1st 1960, the Americans launched the Television Infra-Red Observation Satellite, or TIROS, which "...took 23,000 pictures of the Earth and its clouds over a period of 78 days. Meteorologists the world over were ecstatic." [4] This can be considered the start of the most revealing period so far in man's history where his planetary home was concerned. For the first time, the peoples of the Earth could see just how accurate the early explorers and mapmakers had been, in their portrayal of the planet's major landmasses and seas.

Seven years later two American scientists, F.J. Low and D. Kleinmann, began a search for galaxies emitting energy at infra-red wavelengths and in the following year two more American researchers, Eric Becklin and Gerry Neugebauer, reported their observations of the galactic centre at infra-red frequencies. By 1970, Low and Kleinmann had reported a number of galaxies emitting in the infra-red band, and Neugebauer and his colleague Robert Leighton had completed their survey of the sky at the relatively short infra-red wavelength of 2.2 μm, identifying no less than 20,000 sources in the northern hemisphere alone!

In January 1983, the Infra-Red Astronomical Satellite (IRAS) — shown in figure three — was launched, designed to detect infra-red radiation from space. Carrying a 60-cm reflecting telescope which — along with the infra-red detectors — was cooled to 2 K by liquid helium, this vehicle was a "... joint endeavour by the United States, the Netherlands and Great Britain." [5]

Its beryllium primary mirror had an aperture of 57 centimetres (cms), and there was what amounted to a small laboratory of instruments in the telescope's focal plane. It had a total of 62 detectors, 15 or 16 being used for each of the four infra-red wavelengths. The same segment of the sky was observed by at least two of the detectors, and so a 'true' reading was one that had been registered by both detectors.

During its 10 months of operation it performed splendidly, discovering a large number of infra-red sources among which were eight galaxies. It also discovered evidence of planet formation around stars outside the solar system before — as expected — the liquid helium coolant ran out, in November 1983. In all, this remarkable satellite recorded some 600,000 objects, among which was the asteroid 3200 Phaethon, the source of the Geminid meteorite shower. This was the first such body to be discovered by a space craft.

One of the galaxies unveiled — IRAS F10214 + 4724 — subsequently proved to be the most luminous object ever found in the universe. This IRAS discovery was later studied by a team of American and British astronomers, using ground-based optical telescopes. It proved to be an astonishing 16,000 million light years away from us!

Another discovery was the existence of extremely cold clouds of hydrocarbons — which astronomers termed infra-red cirrus — in interstellar space. Moreover, infra-red radiation from these gas and dust clouds between stars strongly suggested that they were mainly composed of cellulose, the substance of all plant-cell walls and natural fibres, and still the most abundant organic material on earth.

Shortly after IRAS's cryogenic fluid was exhausted, the European Space Agency (ESA) decided to dedicate another vehicle to infra-red investigation: the Infra-red Space Observatory, or ISO, satellite. Given the advances in monitoring technology and space vehicle construction, ISO represented about a 1000-fold increase in overall sensitivity and a 10-fold increase in resolution over the IRAS vehicle.

Launched in November 1995, this vehicle made many important discoveries, undoubtedly the most interesting being that water — that good old basic piece of chemistry H_2O — was much more abundant in the universe than had been thought hitherto. The satellite had an estimated operational life of 18 months and in November 1997, it finally suffered the same fate as its predecessor IRAS: Its cooling fluid was exhausted.

ISO's launch was the culmination of 12 years of close co-operation between Europe's scientific communities and aerospace industries. Consequently, ESA's 2000 Project plans to follow up ISO's success by launching yet another infra-red investigative probe: the Far Infra-Red and Submillimetre Space Telescope, or FIRST, in 2006. Work is already in hand on vehicle development and the investigations will concentrate on the 70 to 1000 micron wavelength.

Presently of course Earth-monitoring satellites proliferate and "Meteosat is Europe's contribution to the ring of geo-synchronous weather satellites that keeps the earth under continuous observation." [6] Positioned over Africa, its orbit being synchronised with the Earth's rotation, this weather-watcher generates images every 30 minutes, its infra-red radiometers taking the temperature of the cloud tops, enabling the build-up of a temperature profile of the planet's atmosphere.

Ground-based telescopes too are also used for infra-red working, they being provided with special interference filters and cryogenic detector systems. The latter eliminate obstructions by infra-red radiation released by the detection equipment itself.

A good example of a ground-based infra-red telescope in the United Kingdom Infra-Red Telescope, (UKIRT), the largest instrument of its kind in the world. Its location — at the summit of Mauna Kea on Hawaii, which peaks at 14,000 feet or over 4,000 metres — is crucial, for atmospheric water vapour is a powerful absorber of infra-red radiation. Equipped with a remote control arrangement, its 3.8-metre mirror has the accuracy to detect even the sub-millimetric waves usually captured by radio telescopes.

Infra-red instruments have been "… used to make maps of the dark terrain of Jupiter's moon Io, to detect a mysterious 'white spot' on Saturn, to observe oceans of oil on Saturn's moon Titan and to observe stars hidden by dust at the centre of the galaxy." [7]

Infra-Red Today

Infra-red technology was — originally — developed for military purposes. As early as 1942 "… EMI's camera-tube department developed an infra-red image converter of which over 250,000 were eventually made." [8] Today, the military connection remains strong, infra-red technology being employed in night-vision equipment and anti-armour ordnance, a good example of which is the Milan anti-tank guided weapon, or ATGW.

Weighing a mere 7 kilos and with a range of 2,000 metres, Milan's goniometer — which detects the infra-red heat component of, for example, a vehicle's exhaust — automatically maintains the projectile's course to its target.

Another area of infra-red technology with military applications is infra-red photography, which is used to detect camouflage, of both personnel and equipment, which it can do in fog and haze, the sort of conditions that not only scatters visible light, but are also all too common on a battlefield.

Infra-red technology has also invaded scores of other areas of activity from archaeology and criminology to search and rescue. We have all seen how such equipment, in the hands of police helicopter crews, have detected intruders, escaping criminals and joy-riders through television programmes such as *Police, Camera Action!* and the more recent *Beware: Bad Drivers*.

In other spheres too such as medicine, printing and (of course) the humble greenhouse, infra-red radiation has proved that it has far more applications than its discoverer ever imagined!

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